EDITORIAL

Exercise Testing

Arthur J. Moss, M.D.

From the Heart Research Follow-up Program, University of Rochester Medical Center, Rochester, New York

Earlier this year, Dr. Robert A. Bruce, the father of modern exercise stress testing and exercise cardiology, died at age 87 from complications of leukemia. Exercise testing is one of the foundations of noninvasive electrocardiology, and stress testing with ECG monitoring has become our most reliable noninvasive diagnostic test for screening healthy subjects for heart disease and for evaluating cardiac patients for the extent and severity of their heart disease. A brief history of exercise testing and its present status will provide a background for future direction.

MASTER'S EXERCISE TOLERANCE TEST

In 1929, Master described a simple two-step exercise tolerance test with measurement of heart rate and blood pressure for evaluating circulatory efficiency.[1] ECG monitoring was subsequently added, and in 1941, Master, in collaboration with Jaffe, described ECG changes after the exercise test for detection of myocardial ischemia from exercise-related coronary insufficiency.[2] By 1955, Master's Step Test became the standard approach for evaluating patients with heart disease, but limitations related to the low level of exercise stress and the absence of heart rate and ECG monitoring during the exercise began to be increasingly appreciated.

HARVARD EXERCISE STEP TEST

The Harvard University Fatigue Laboratory introduced the Harvard Step Test in the early 1940s and involved stepping up and down on a 20-inch platform 20 times a minute for 5 minutes. Although the test was somewhat more vigorous than the Master's Step Test, this testing approach did not gain wide applicability in clinical medicine. A modification of this test by Kaltenbach has been used in Germany.[3] The subjects use the muscles of their arms and legs during the stress test, and the speed of stepping up and down can be regulated with a metronome. The major limitation of this test is that the blood pressure cannot be monitored during the test.

BICYCLE EXERCISE TEST

The bicycle test is more popular in Europe than in the United States, probably a reflection of the different frequency of the use of bicycles as a means of transportation by adults in the two geographic regions. Bicycle testing usually involves an electronic brake to augment the workload that is measured in watts. The upper portion of the body including the arms and thorax are quite stable during the bicycle peddling, and good-quality ECGs are usually obtained with little if any muscle artifact during the exercise.

TREADMILL EXERCISE TEST

The treadmill exercise test, commonly referred to as the "Bruce protocol test," has a number of advantages for the speed and grade of walking can be progressively adjusted.[4] A copy of Dr. Bruce's classic article on exercise testing is presented in the History of Electrocardiology section of this issue of *Annals*. In the traditional Bruce protocol test, the starting speed of 1.7 miles/hour at a 10% grade, equivalent to an oxygen consumption of about 4 METS, can be done by almost all ambulatory subjects. The speed and grade are progressively increased at 3-minute intervals to 5 miles/hour at an 18% grade with a cumulative time of 15 minutes or more. At 15 minutes of exercise, the maximum

Address for reprints: Arthur J. Moss, M.D., Box 653, University of Rochester Medical Center, Rochester, NY 14642. Fax: (585)-273-5283; E-mail: heartajm@heart.rochester.edu

energy achievement is in the range of 14 METS, with oxygen consumption of 50 mL/kg per minute. Normal standards for healthy adult men and women as well as for male cardiac patients have been established. Several variations on the Bruce protocol test exist including the Balke (constant speed with grade gradually increased),[5] Astrand (5-minute warm-up with multistage run to exhaustion),[6] Sheffield,[7] and Naughton protocols, to mention but a few.

PRESENT STATUS AND FUTURE DIRECTION OF EXERCISE TESTING

Presently, treadmill exercise testing with blood pressure and ECG monitoring of heart rate and ST-segment changes are utilized primarily to identify patients with underlying coronary disease, to evaluate progression of coronary disease in patients with known ischemic heart disease, and in the regulatory evaluation of new antianginal drugs. Changes in the exercise-induced QRS score can provide improved precision in the detection of multivessel coronary disease.[9] As ECG monitoring has become more sophisticated with signal averaging, T-wave alternans, T-wave lability, and QT/R-R dynamicity, stress testing is now being used to identify patients at risk for life-threatening arrhythmias so they can be better stratified for implantable defibrillator therapy. The duration of exercise achieved and the associated oxygen consumption have become important endpoints in the regulatory evaluation of new drugs and devices (biventricular pacing) for treatment of patients with heart failure. Dr. Robert Bruce has left an important legacy in the detection and evaluation of patients with heart disease, and we are all indebted to him for the insights and direction he has provided.

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